THE INAUGURAL GEORGE F. SOWERS LECTURE

The Challenges and Opportunities That Lie Ahead in Teaching The Practice of Engineering in the Research University

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DEDICATION

This paper is dedicated to Ms. Frances Sowers, the life-long partner of George Sowers, and a great person in her own right. My wife, Anne, and I have been blessed to have her as a friend for many years.

ACKNOWLEDGEMENT

A number of individuals contributed to the thoughts expressed in this paper. The list begins with George F. Sowers who was a teacher and a friend from the day I took my first course with him in 1963. It also includes other great teachers and mentors, Alex Vesic, Mike Duncan, Jim Mitchell and Harry Seed.

Special thanks goes to Ward Winer, chair of the Woodruff School of Mechanical Engineering at Georgia Tech for suggesting the theme of "the practice of engineering," and providing other important insights; suggestions by Jean-Lou Chameau, Dean of the College of Engineering at Georgia Tech, who was also instrumental. Finally, I would like to thank Carol Jones for her assistance and patience in producing this paper.

INTRODUCTION

George Sowers was a renowned engineer and educator who excelled in teaching engineering from the perspective of professional practice. His textbooks embodied the notion that good engineering requires a broad understanding of issues, and he frequently reminded us that most failures involved simple oversights rather than lack of access to better theories. George understood that the key to the education of an engineer was more than theory, more than design, but rather how these elements could be wrapped within an understanding of the practice of engineering.

George began his university career at Georgia Tech in 1949, and he maintained an affiliation with this institution for almost 50 years. His career spans a period of rapid evolution of the research university in the United States, and indeed the world. Georgia Tech is an example of the change that occurred for those universities that made the commitment to incorporate research as a principal part of their mission. When George came to Georgia Tech, it was a regional university where research was not emphasized. When he retired, Georgia Tech had become a major research university with an array of international linkages.

Georgia Tech's transformation parallels that of many sister institutions in the U.S. and abroad. During the transformation, expectations of faculty changed from a focus on teaching undergraduates to one with an emphasis on research, publications, development of graduate courses, and advising of graduate students. While many benefits accrued from the development of the nation's university research programs, the need to teach the practice of engineering is as important as ever. Yet at the same time, we seldom hire faculty today at a research university based on the ability to understand or teach engineering practice. In the short term we may not notice the effect, but in the long run there is a danger that engineering education will become an instrument that serves university needs, but one that is irrelevant to our external constituencies.

> ***"Who will train our students to carry out the indispensable function of general civil engineering? Will they be teachers who understand design and construction....Or will they be persons with no-first-hand knowledge of practice?"***
>
> **Ralph B. Peck**
> **Professor Emeritus, University of Illinois**
> **Geo-Institute Conference, Logan, UT**
> **July 1997**

In the abstract, there is surely an agreement that teaching the practice of engineering is important, but this comes at a time when research universities face many profound issues. They range from the mundane such as how to stay afloat financially, to how teaching and learning will occur in an era of a revolution in educational and information technology. Indeed, some visionaries see a struggle ahead for the very survival of the traditional university:

> ***"30 years from now the big university campuses will be relics. Universities won't survive. It's as large a change as when we first got the printed book."***
>
> **Peter Drucker**
> **Management Consultant**
> ***Seeing Things As They Really Are***
> **Interview by Robert Lenzner and**
> **Stephen S. Johnson**
> **Forbes Magazine, March 10, 1997**

> *"..... The pace and the nature of the changes have become so rapid, so profound that social institutions which are characteristic of the past, and I include in that corporations, governments, and educational institutions like universities, are having increasing difficulty in sensing, understanding, and preparing for change...."*
>
> **James Duderstadt**
> **President Emeritus and University Professor of Science and Engineering**
> **University of Michigan**
> **NACUBO Senior Financial Officers Conference**
> **May 1997**

These views have a very real edge to them. But as with all times of major challenge, there is great opportunity as well. In fact, there are exciting changes afoot, which, if we take advantage of them, can make the teaching of engineering practice more relevant and interesting than ever before. To make the most of our circumstances, we must consider the needs of engineering practice not in the context of the university today, but what it is likely to become in the future.

WHY TEACHING ENGINEERING PRACTICE IS IMPORTANT

Technology is steadily becoming more pervasive in our society and with it the importance of an engineering education. To an extent such an education is gained by learning the concepts of design, but it is much more. The larger context is that of engineering practice which encompasses elements of human endeavor, including political pressures, ethics, business management, communication, leadership, and the need to find honest compromises working within economic and time constraints. All of these elements are usually found in one degree or another in a suitably broad engineering project, and learning how they interweave in design, manufacturing and construction. This component of education provides a student with useful, if not essential, knowledge in life after the university.

> *"Our system of education and training must ... equip tomorrow's engineering and science professionals to shoulder growing responsibilities and pursue emerging opportunities."*
>
> **Joseph Bordogna**
> **Acting Deputy Director**
> **National Science Foundation**
> **National Academy of Engineering,**
> **The Bridge, Vol. 25, # 4, Winter 1995.**
>
> *"Our students...need more exposure to the integrative aspects of engineering design and practice, and to the analysis and management of large-scale, complex systems."*
>
> **Charles Vest**
> **President**
> **Massachusetts Institute of Technology**
> **National Academy of Engineering,**
> **The Bridge, Vol. 25, #4, Winter 1995.**

Having a student educated about the fullness of the practice of engineering is the crux of our educational process. The National Research Council's Board on Engineering Education in their 1995 report, "Engineering Education – Designing an Adaptive System", provided recommendations for curricula to achieve this. However, this report does not take into account the changing context of information technology or that of the modern research university. To get at the issues, we need to first consider the context.

CHANGING DEMANDS ON INDUSTRY

One of the major "consumers" of research university engineering graduates is industry.

In the United States in the 1980's the industrial and corporate sectors were swept by a seachange and those companies that survived did so by undertaking drastic measures and changing their cultures. While the circumstances facing industry were shaped by a rapid evolution of the global economy, the end of the cold war also played a fundamental role. In the U.S., this resulted in elimination of large government programs and entire segments of our economy literally disappeared. New products and services had to be shaped using alternative technologies and skill sets. This led to the remarkable development of the era of entrepreneurs, start-up businesses and the venture capitalists, and its profound effect on new job production and wealth creation.

The reincarnated post-cold war industry found it needed employees who were not only technically competent, but also were adept at working in teams, flexible in their attitudes about work assignments, adaptable and creative in problem solving, understanding of the global economy, and able to communicate their ideas to both management, labor and the public. This need was transmitted to universities and engineering colleges, where the message was delivered that the engineer educated with even the best pure technical skills was not good enough.

The new global economy meant that alliances and collaboration replaced an ethic of individualism and isolationism. A good example can be found in the design and construction of the Boeing 777, which was achieved in record time taking the fullest advantage of new technologies and the concept of working in teams across national and company boundaries.

> ***"the 777 is one of the world's largest and most complex machines. Creating it required the design and building of an object made of 132,500 uniquely engineered parts with a total of three million items. More than half of the airplane was manufactured by 487 U.S. suppliers and 58 suppliers in twelve nations. To facilitate the design and building of the 777, Boeing implemented a team process. Members of teams included representatives from design, analysis, manufacturing, tooling, materials, and customer service—plus vendors and customers. Powerful digital computer-aided design technology enabled designers to create the 777's parts and systems as three-dimensional solid images. Parts and systems designs were electronically pre-assembled and viewed as solid images on workstation display screens, eliminating the need for a costly full-scale mockup of the airplane."***
>
> **Philip H. Abelson**
> **Deputy editor of engineering and applied sciences**
> ***Science* Magazine**
> **William D. Clary Lecture,**
> **22nd AAAS Colloquium on Science and Technology Policy, April 23-25, 1997, Washington, DC**

The new market incentives and design technologies are having a profound effect on the way companies do business. So too is the introduction of international standards such as ISO 9000 and ISO 14000, which force industry throughout the world to conform to a common set of high levels of performance.

Industry is forever changed by its experiences in the recent past and it expects engineering education to respond to its new needs.

CHANGING DEMANDS ON GOVERNMENT

University and government sectors lagged behind industry in being overcome by a new order of things. It was not until the 1990's that government and universities began to see significant impact from developments of the global economy. The impacts are still occurring.

At the federal level, efforts to balance the budget, demands to control government spending, and the dismantling of cold war programs led to a tightening of funding for research programs. This placed faculty at research universities under added pressure to secure funding to not only sustain research efforts, but also to maintain graduate enrollments. In addition to funding issues, a growing movement for accountability placed a new patina on government-university relations leading to restrictions on how research funds could be used and mounting paper work.

Added to the pressures from the federal level, many states encountered budget problems, and this often led to severe funding reductions for higher education. In the early 1980's higher education typically received 15 or 16% of a state budget, but by the mid 1990's this dropped to 9 or 10%. An ominous trend occurred in many states where the funding for state prisons exceeded that for higher education.

CHANGING DEMANDS ON UNIVERSITIES

The dawning of the 1990's followed a period of remarkable growth of the research university, a time when support was strong and the Cold War provided an underlying motivation for expenditure of massive levels of federal funds for engineering research.

The subsequent years have been a less auspicious time for research universities, with the arrival of an array of new expectations from the federal government, state legislatures, parents, and average citizens. Questions have been raised about issues that lie at the basic culture of the research university, including:

- Relevancy of curricula and research results
- Allocation of faculty time to teaching and advising
- Excessive dominance of disciplines on teaching and research
- Political correctness and affirmative action
- Faculty governance and tenure
- Allocation of intellectual properties

In Sunbelt states, projections of large increases in student enrollment dominate the attention of planners and university administrators. Finally, the revolution in telecommunications and education caught up with its hype, and began to seriously impact educational delivery. Virtual universities such as Phoenix University, the Western Governors Virtual University and the Open University of London, have seen their enrollments grow rapidly and are beginning to compete with traditional universities for students.

Squeezed by budget constraints from the federal and local level, pressured to be accountable to more constituencies, dealing with past policy mistakes, and attempting to respond to rapid technological changes, the research university faces a tough climb onto a mountain that does not have an obvious path to the peak.

TEACHING ENGINEERING PRACTICE IN THE MODERN RESEARCH UNIVERSITY

The research university today finds itself in an environment where many of the tenets of its framework are being tested. Finding the means to address our need to teach engineering practice in this context is no easy task and will require a creative and multi-pronged approach.

Several recent papers about the future of the research university have suggested that for added relevance university programs should move closer to industry and society.
One such recommendation came from a recent meeting of CEO's and educational leaders who speculated about the future evolution of the relationship between universities and global industries:

> ***"The result of this brainstorming session was a new "Model of the Global University" ... in the global environment we just described, academe and industry will converge."***
>
> **Philip Condit, president and CEO of the Boeing Company and R. Byron Pipes, president of Rensselaer Polytechnic Institute.**
>
> ***The Global University.*** **Issues in Science and Technology. Fall 1997.**

This recommendation was in response to the perceived need for quick response by universities to the educational needs of global corporations in an environment of rapid change.

Convergence of the university with industry is a debatable concept, because the university is defined by the very independence that allows it freedom of inquiry. Yet, there is no question that the distancing of our universities from the realities of our world, and the over-reliance on federal support for research, has led to poorer understanding of engineering practice and less attention to the teaching of it. To paraphrase the old Protestant hymn, "Just a Closer Walk with Thee," strategically designed linkages to bring students, faculty, administrators and the university closer to "the real world" does create a focus towards the teaching of engineering practice. This also applies to research, which should not have to be a casualty in the process. Also, it relates to the increased use of technology in teaching because universities already lag much of industry and business in integrating technology into engineering. As a general theme, reducing the distance of our engineering programs from industry and society would appear to be a healthy step towards improving our students' understanding of the realities of engineering practice. There are many steps in this process, and some of the more important ones will now be presented.

ADAPTING TO THE INFORMATION TECHNOLOGICAL REVOLUTION

For over a decade computer usage in universities has been pervasive, but it was not until the example of the design of the Boeing 777 that the true power of networked computers and compatible software was shown. Many research universities have used advances in telecommunications to develop distance learning networks, but it was not until the emergence of private virtual universities that the power of delivery of assemblages of courses from various sources was apparent. Universities have also experimented with the use of educational technology for some time, but it is the near revolutionary expansion of use of the internet for information access by our students that is awakening us. All of this leaves the traditional university in a position of waiting for the starter's gun in a race that has already begun.

Universities are responding to the challenges, and there are promising signs including the network-based wiring of campus infrastructure, requiring students to own computers, and creating on-line course materials. Yet much more is to come in the form of on-line, asynchronous, on-demand learning technology, computing and information systems of far greater power than today's, classrooms with the capability to directly transcribe lectures to students' computers, and new software that allows for collaborative design between remote teams. These developments are already being used in pilot applications at Georgia Tech and other institutions, and will be broadly available soon.

Choosing which of the new technologies to implement and deciding how to go about using it raises many issues. It calls for a meeting of the minds between those who are involved. At one level, this would appear to be an ideal opportunity to bring together university and industry leaders in forums where both sides hear the views of the other, and develop consensus on the future course universities plan to take. A second part of this initiative would be to hold workshops where experts on design and engineering practice would be joined by top cognitive scientists, computer scientists and communications experts to consider the issues. These workshops would focus more on technologies and less on the broad concepts of the university/industry forums. The end result of these meetings would provide a public basis for future directions that can be debated and sharpened over time.

INTRODUCING THE ENTREPRENEURIAL CULTURE INTO ENGINEERING EDUCATION

Future engineers will need to be prepared to work in a global economy different than that most of our faculty appreciates. The present literature is dominated by the culture of the large corporation, the traditional consulting practice, and a world of centralized computing. With the emergence of high-speed electronic commerce, start-up businesses funded by venture capital, and decentralized computing and communications, a new environment is unfolding outside of the gates of the university. Engineering education is at risk if it chooses to ignore this, since it represents the kind of exciting frontier that the best students will migrate towards. Universities, and particularly engineering programs, can position themselves to take advantage of the emerging entrepreneurial culture by linking programs in computing science, business management and engineering. Some are already doing this, but no one is moving fast enough to catch up with the developments that are in process. Also, the picture is not complete by focusing on internal restructuring since the infrastructure outside the university is leading the charge, and again, finding the means to move closer to this external world will be helpful. This calls for using adjunct faculty who bring direct experience, and even development of centers for business incubation on the campus so the process can be seen first-hand.

RECOGNIZING SOCIAL RESPONSIBILITIES ROLE OF SUSTAINABLE TECHNOLOGY

Engineering curricula are designed to inform students about their social responsibilities through courses in the humanities, social sciences and ethics. However, the emerging field of sustainable technology can do as much, or more, to achieve this objective since the topic matter allows first-hand contact with social issues within the context of engineering design and practice. The importance of sustainable technologies and the widespread implementation of them were underscored by the recent Kyoto Global Climate Conference. No political agreement could be reached that would slow the pace of pollution by countries with developing economies, leading to the conclusion that new sustainable technology is the key to a "greener" planet for the foreseeable future. As such, this field needs rapid development and incorporation into engineering curricula.

Sustainable technology cuts across all engineering curricula and can be taught in terms of principles, theory, design or practice. At Georgia Tech our Center for Sustainable Technology was created five years ago and has introduced basic courses that hundreds of our students are taking. The theme of sustainable technology is one that we have adopted to focus our efforts in research. This approach is spreading as more engineering colleges are shaping efforts in the area, an encouraging sign.

INTER-MIXING PROFESSIONAL PRACTICE INTO FACULTY AND DEPARTMENTAL RESPONSIBILITIES

Teaching the existing and emerging tenets of engineering practice requires that faculty have experience with it. Yet, today's new faculty often come to the teaching profession with little breath or experience in engineering practice. Fortunately, understanding of the practice of engineering comes from more than a single faculty member, since the sum total of the education of a student comes from his or her experience with the entire curriculum and the totality of the faculty.

Thus, the responsibility for engineering education of students lies both with individual faculty and the collective faculty. The latter point is important since some in practice have the unrealistic expectation that each and every faculty member should come to their positions with industrial experience. While this would be desirable, it is not practical, and not necessary, if the curriculum as a whole and the faculty efforts behind it are designed appropriately. To address the needs of teaching the practice of engineering, each academic unit has to infuse the subject matter in many places in the curricula and insure that the faculty as a whole are steadily growing in their abilities to teach it. Some elements that capture this theme follow:

Adapting to New Ideas. As noted in my earlier remarks, the world in which our engineering graduates will practice is changing relentlessly. While not all faculty need to be expert in all of the issues, departments and colleges need to see to it that curriculum coverage is provided for their students and that enough faculty are prepared to achieve the desired objectives, and processes are in place to prepare younger faculty for their future roles.

Consulting. The process of engagement of faculty with industry and society comes when reasonable levels of consulting are regularly encouraged, and even expected. This may seem obvious, but having had the opportunity to review hundreds of faculty dossiers, too few are serious about consulting, or are not proud enough of it to report it. It should be clear from the department and its leaders that one of the elements for faculty advancement is an expectation that some level of consulting or involvement with engineering practice is important.

Additionally, senior faculty need to provide mentoring for young faculty and to selectively create opportunities for them in consulting. There is no need to rush young faculty towards consulting activities, and indeed, too much too soon can be fatal to the academic career. The sound advice given to me many years ago by the geotechnical great H. Bolton Seed was that "good consulting work will come if you do your work well…don't rush into it. The quality and diversity of the outside work you do is important to your growth."

Hiring Engineers with Industry Experience. Departmental efforts to incorporate the teaching of practice can also be improved by the hiring of a number of engineers whose primary experience lies in the industry and the profession. Such individuals however need to have special skills and an ability to work within the professorate. This calls for a demonstrated involvement with professional activities, at least some ability to participate in research and the temperament to be a first-rate teacher.

The Curriculum. The most obvious curriculum device to teach practice is a well-designed capstone course taught by faculty with experience. It needs to be designed to include new dimensions as mentioned previously. Stand-alone design courses also have a role, but as with capstone courses they tend to come late in the student's academic stay. Leading up to this course, practice oriented material can be included in the problems that are solved in many engineering science courses. While this requires work, it is worth the effort. The bottom line is that the entire curriculum should be considered to see that the totality of the student's education brings an orientation towards the practice of engineering.

Cooperative Education and Internships. On the job experience can be a powerful part of the education of engineers. The best such opportunities are represented by cooperative education where the student participates in an organized program of alternating work and study terms. This allows for relevant experience to be obtained in circumstances where mentoring and training are available.

Research. One of the best means to encourage closer linkages between research universities and industry is through joint research activities. In the abstract, this is an ideal place for the linkage since universities are well equipped to do research and industry needs research to remain competitive. In the real world, research between universities and industry in the U.S. is far less than that with the federal government, and there are many reasons for this. On an average, industry sponsorship of university research funding in the U.S. is only 7% of the total.

A few universities have a higher participation rate of industry in their research-funding base, but even here, 20% is on the high side. This is not acceptable and to redress the situation requires a new approach by both universities and industry. This calls for attention to processes for definition of intellectual properties, rights to publication, and formation of an integrated approach to contracting so that large numbers of small contracts does not inundate universities. Also, collaborative approaches between federal and state governments and universities and industry need to be encouraged since these help lead to increased interaction.

Finally, a number of universities are finding advantages in linking their research closer to industry through the creation of on-campus business incubators. Georgia Tech has such an incubator and it now claims graduate companies with annual expenditures of $500 million and 2500 employees. This mechanism brings commercialization expertise directly to faculty and provides the link for university research outcomes with the venture capital community. It also gives the campus a laboratory for students to observe the process of start-up business and its interaction with venture capital.

International Studies. It goes without saying that engineering practice today is significantly affected by the global economy. This requires that each engineering graduate leave the university with an understanding of the international issues that affect our world. This can be provided through study-abroad programs, inclusion of international perspectives in the curriculum, guest speakers among others. The university experience needs to be inclusive enough to allow the engineering graduate to be able to compete with those from business or policy programs.

CONCLUSIONS

George Sowers had a remarkable career in which he stood as an exemplar for the teaching of the practice of engineering. His tenure spanned a period in U.S. and world history that saw the development of today's research university along with many advances in technology. Yet the dramatic changes of the recent past are likely to be small compared to those that lie ahead. It is up to this generation to lay the groundwork for a future that will maintain and enhance the legacy of great faculty like George Sowers.

George would remind us that a constant for the past and the future is that our students still need to be educated in the art of the practice of engineering. The world has an ever-growing need for engineers who can help provide leadership in a society daily more dependent on technology. Yet there is no doubt that the education of our students in engineering practice is more tenuous than it was in the past, and even problematic for the future. Some of this can be attributed to side effects of the growth of the research university and its dependence for research support on the federal government.

The challenge is to create a new educational milieu for our students at a time when the pace of change is rapid, the future is hard to predict, and the research universities struggle with their own major challenges. Indeed, some prognosticators are predicting the demise of traditional universities because of their inability to adapt quickly enough. I, for one, do not believe this will occur, but we will be successful only through significant effort and openness to new methods of teaching and learning. Under these circumstances, we have to look to use all available resources and work in concert with entities that share in our destiny.

To this end, we need to "move closer" to industry and society and reduce the gap created by our over-reliance on federal research support. The term industry in this discussion should be seen not only as traditional corporations and consulting firms, but also the exciting world of start-up ventures. "Moving closer" to industry and society involves many aspects of our operations, including:

- Adapting rapidly to new collaborative communication, computing and educational technologies.

- Integrating experiences with the growing entrepreneurial business world

- Developing a greater respect for social responsibilities of engineers; a primary vehicle for this endeavor can come through education about sustainable technology.

- Re-examining the totality of our engineering educational environment to insure that we provide for the teaching of engineering practice.

These tasks are easily said, but will require efforts that are going to be difficult and costly. Engaging our industrial and societal partners to help us chart our course is essential. At the same time, university administrators need to understand the importance of the issue even as they struggle with the challenges they face. I believe all of the parties can be best engaged if a positive and forward-looking agenda is set.

The stakes are high and concern nothing less than the future of the engineering profession. I am sure George is up there watching and expects no less than our best.